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# COMPUTATIONAL ANALYSIS OF PASSIVE COOLING TECHNIQUE APPLIED TO A ROOM UNDER NATURALLY INDUCED FLOW

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***Abstract***

***In 21st century, the global warming has become great threat to mankind. The Air Conditioner became mandatory for room cooling in all the households which releases poisonous gases like CFCs and CO2 and also depends on electric power. The best promising alternative for less energy consumption is the passive cooling technique. Passive cooling (PC) is the process of reducing the temperature of a specified region without using electricity. In this paper, we discussed about the passive cooling of a room with the help of natural convection and solar chimney. The set up consists of a plastic pipe, copper pipe, solar chimney and a room. The solar chimney reduces the density of the air in the chimney, due to this density difference, the cool air enters the room and the air present in the room flows into the chimney. The atmospheric air is passed through the copper pipe which is placed underground near the water resource. So the heat available in the atmospheric air will be convected naturally through the walls of copper pipe to the water. In this experiment, we achieved about 1.5 to 2K of temperature reduction.***

***KEYWORDS: CFD, Flow behaviour, Passive Cooling & Solar Chimney***

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**Original Article**

## INTRODUCTION

Energy consumption in the world is increasing rapidly which causes enormous release of poisonous gases. Since The potentials of solar heating for passive cooling is still not clear. The latent heat stored by the vaporized water in summer is known as evaporative cooling and Effective radiation from horizontal surface is radiative cooling [1]. The average peak temperature drop of the reflective technologies,

**Nomenclature:**
P – Pressure (bar)
V – Velocity (m/s)
Z – Datum (m)
C – Constant
Q – Heat Transfer(W/m$^2$)
h – Convective heat transfer coefficient(W/m$^2$K)
T – Temperature (K)
A – Surface area (m$^2$)

**Greek Symbols**
g – Acceleration due to gravity (m/s$^2$)
$\rho$ – Density (kg/m$^3$)
$\Delta$ - Difference

**Abbreviations**

| | |
|---|---|
| PCT | Passive cooling technique |
| HT | Heat Transfer |
| HTC | Heat Transfer Coefficient |
| SSPCM | Shape Stabilized Phase Change Material |
| PCM | Phase Change Material |
| HE | Heat Exchangers |
| UDF | User Defined Function |

There are various PCMs available in the market. But some studies give the greenery, evaporative systems, cool ponds, cool roofs, pavements, green roofs is brought down by maximum of 2K with the help of mitigation technology. For the same projects, the average ambient temperature drop is nearly 0.74K [2]. A solar chimney can be used for natural ventilation to save energy. The parameters taken for study of the solar chimney are: angle of incident, wind speed, ambient temperature etc. The result shows the reduction in cost and increase in safety [3] and Wind catcher is one of the oldest passive cooling system that is still using now as an alternative to the active cooling. Since the heating and ventilation systems using 60% of the energy consumption in buildings, a new design and approach of wind catcher is used mainly focusing on the indoor air quality and thermal comfort. Earth to air HE and HT devices used for night cooling. [4]. When we talk about night cooling, the phase change material (PCM) comes into picture. Best PCM for a particular application. SSPCM is a composition of Paraffin (80%), high density polyethylene (15%) and expanded graphite (5%). This PCM presence leads to decrease the internal temperature fluctuations in heating conditions. [5]The most affordable passive ventilation alternative is the solar chimney to increase thermal and ventilation performance.

The optimum flow rate of air is achieved by 88.2% in day time when the dimensions of solar chimney are $45^0$, 1.4 m length 0.6 m width and 0.2 m air gab. The solar chimney provided at the east-southern part of the building gives maximum ventilation rate and also found that every solar chimney provides necessary ventilation.[6][7]Experiment, Analytics and simulation of solar chimney, hybrid systems and geographical shows good results even with small scale experiment and CFD analysis. [8] The peak load on ACs in buildings, reducing the size of AC and also the period for which it runs. The passive cooling technique greatly reduces the power consumption by Household Air Conditioners and maintains the thermal comfort inside the building. [9]. Any proposed model can be implemented into ansys fluent, based on user defined functions (UDF), so that we can compare the results with the practical model [10]. In the case of heat transfer, the heat transfer coefficient is very important to analyse radiant heating/cooling system. For more accuracy, we have to estimate the HTC On the basis of heat cold emitted room [11]. Effect of thermal conductivity on convective heat transfer is studied by [12]. G. Mageshwaran et.al have explained the importance of alternate cooling technique requirement, and successfully implemented one such system for vehicles using waste heat energy from exhaust gas.

## METHODOLOGY

### Conceptual Design

The room has 2 openings namely inlet and exhaust. The exhaust is connected to the solar chimney which gets heated from sun light. A conductive material or glass may be used as the chimney wall so as to focus the incoming solar radiation into the chimney area. As the air inside the chimney gets heated, the density of the air reduces and tries to escape out at the top of chimney.

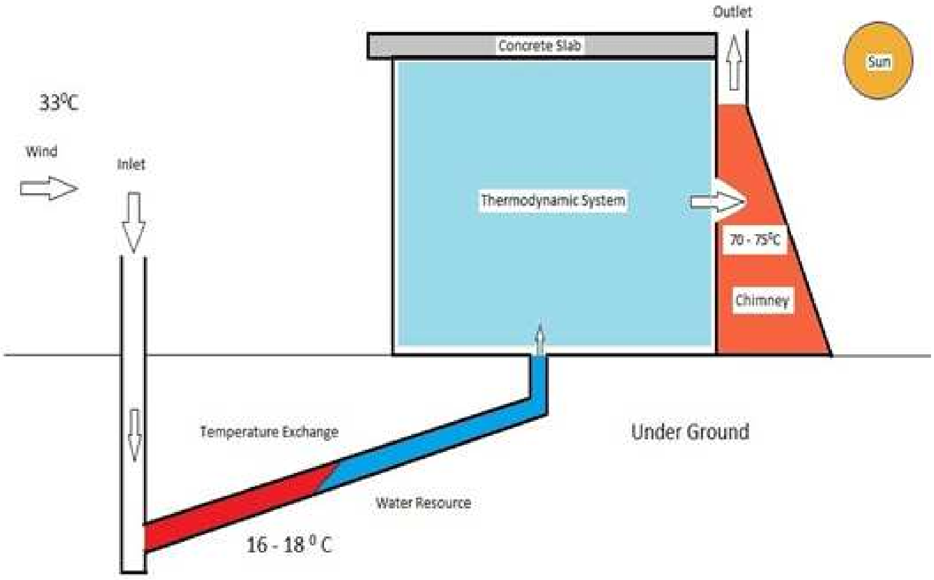



**Figure 1: Conceptual Sketch of the Design**

As a result, pressure drop occurs at the exhaust and air inside the room starts to move towards chimney area.

Inlet of the room is connected to the long pipe which is taken all the way through the underground or drainage water and opened into the atmosphere as shown in figure 1. The air exchanges heat from the surrounding soil or water and enters the room.

**Formulae**

Bernoulli’s Principle: Bernoulli's principle states that an increase in the speed of a fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy.

**Bernoulli’s equation:**

$$\frac{P}{\rho g} + \frac{V^2}{2g} + Z = C \tag{1}$$

Where $\rho$ = density of air (kg/m$^3$)

V= velocity of air (m/s)

g = Acceleration due to gravity (m/s$^2$)

Z = Height from the ground level (m)

C = Constant

**Convection:** Convection is the movement of groups of molecules within fluids such as liquids or gases. Convection takes place through advection, diffusion or both.

**Convective Heat Transfer Equation**:

$$Q = hA\Delta T \tag{2}$$

Where Q = heat transfer (W/m$^2$)

A = Surface area (m$^2$)

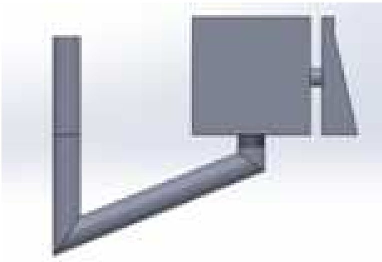
ΔT = Temperature Difference (K)

h = convective heat transfer coefficient ($W/m^2K$)

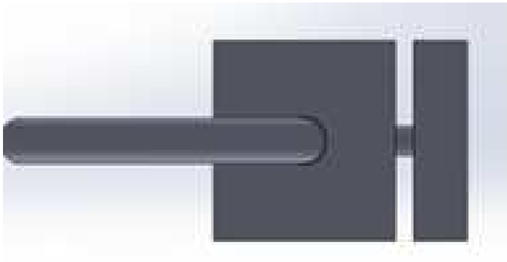
Using above equations, we can do calculations for this case. So there equations are programmed in ansys, to do such calculations with ease for complex parts.

**Design**

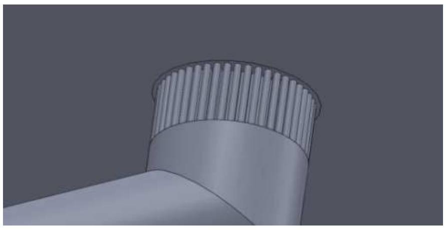
To do the analysis, first we created the 3-D model in solid works as shown in figures 2(a), 2(b) and 2(c). For analysis, the flow occurring places need to be designed as solid part. So, the inverse or inside shape is designed in solid works. The main commands used in solidworks are Sketch, Extrude, Sweep, Split Plane.



**(a) Front View**



**(b) Bottom View**



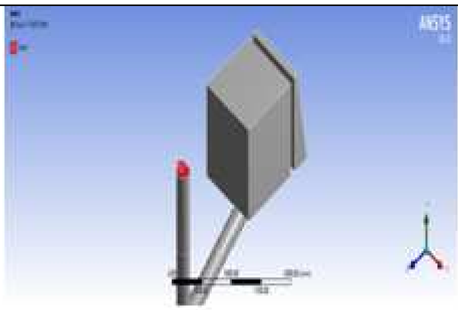
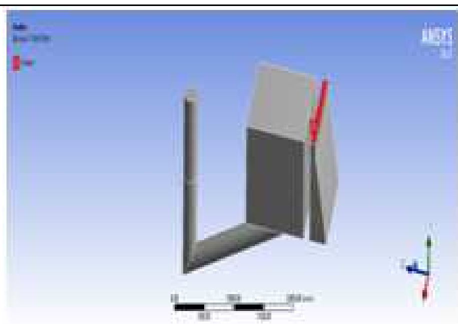
**(c) Honeycomb Structure**

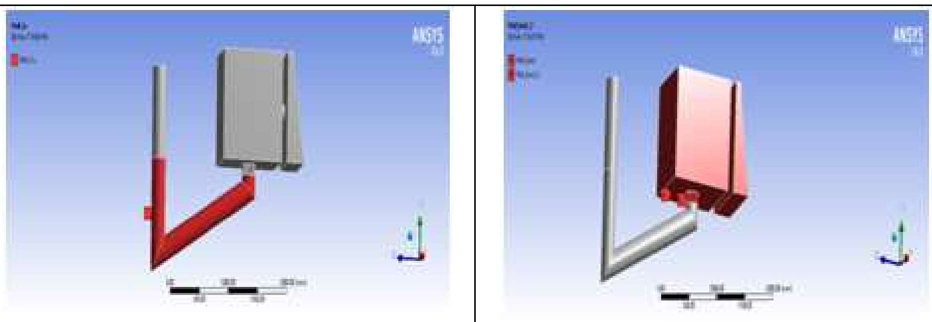
**Figure 2: Different Views of the Design**

Figures 2(a) and 2(b) shows the front and bottom views of the 3-D design. In both the figures, the pipe sections, angled connection of copper pipe and a plastic pipe are shown. The angle maintained of the copper pipe with respect to the horizontal is $60^0$.

Specifications: Room Volume = 1 $m^3$

Angle of Underground pipe = $60^o$ w.r.t horizontal

| | |
|---|---|
|  |  |
| a) The Inlet where the Atmospheric Air is Taken in | (b) Shows the Exhaust Opening where the Hot Air Leaves from Chimney |



(c) the Copper pipe where the heat from atmospheric air transfers to the cold water available under ground

(d) ) is the room and solar chimney.

**Figure 3: Naming Boundary Conditions**

## ANALYSIS

The created model is exported to ansys for fluid flow analysis in fluent.

In Geometry, we import the pre-designed part into the ansys software, so that we can proceed with our well-built design.

In meshing, we mesh the entire part according to our requirement, specifying Coarse or medium or fine. Here we give the name to the particular walls so that we cannot confuse later. Figure 4 shows the fine mesh for the design.

**Table 1: Mesh details of the Design**

| | |
|---|---|
| **Number of Nodes** | 960898 |
| **Number of Elements** | 4532490 |

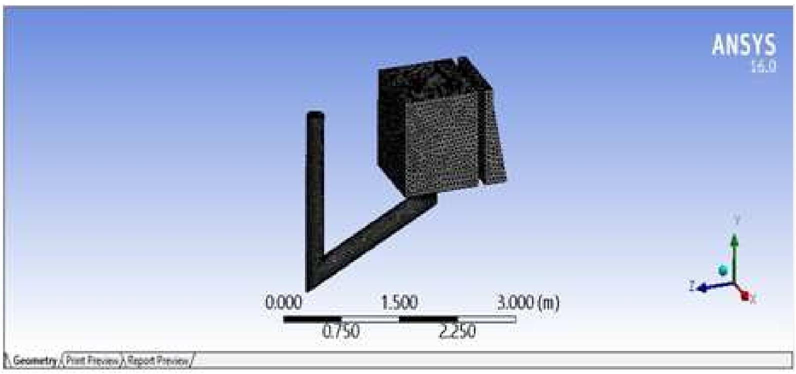



**Figure 4: Meshed View of the Design**

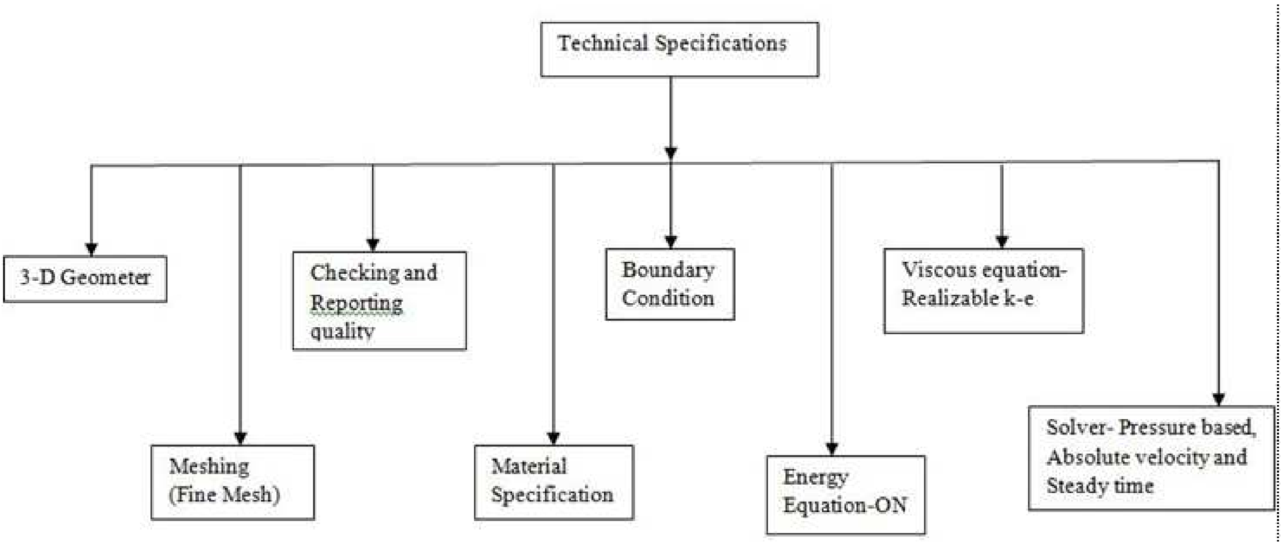
In setup, primarily we will check the meshing and also the quality report. Once it's been ok, the next step is the material specification. In material section, we will import all the required materials that are to be used in the design.

The next step after setup is the solution where we will give the boundary conditions, material specifications and setting up equations according to our requirement. After this, we have to set the number of iterations and reporting interval to get the convergence point for the optimum results. The more number of iterations gives us the more accurate results.

Now we run the calculation so that the software will perform all the required operations to give results.

We will select the contour based results for better understanding. Contour is an outline representing or bounding the shape or form of something.

**Table 2: Stages of Design and Analysis**




## RESULT AND DISCUSSIONS

After applying passive cooling technique to the given design, the following results have been noted. The temperature reduction inside the room is observed. In figure 5(a) and 5(b), the temperature contour of overall system is shown. A plane of colour contour has been generated in order to measure the temperature at various points inside the room as shown in figure 5(c). In that plane, a probe can be places anywhere to read the temperatures at different locations on the plane. Therefore, the temperatures are noted at various points and tabulated in Table 3. The analysis also shows the pressure distribution throughout the design. The pressure contour is shown in figure 6 and the velocity of the air is also shown by a velocity contour in the fig 7. The pressure variation throughout the process is clearly shown. The pressure gradually decreases from atmosphere to the room inlet. A minimum required pressure is maintained to allow the flow.

For solving the above problem, we used energy equation and viscosity equation. The energy equation is set to ON and the viscous equation is set to ‘realizable k-e, Enhanced wall Fn.’ The pressure-based, absolute velocity, steady time solver is used. The materials used are, Fluids- air, Solids- aluminium, steel, copper, calcium oxide. After setting 20 numbers of iterations with 1 interval, the calculation has done and results are noted. The air density is 1.1 kg/m$^3$ and the atmospheric air velocity is 3.48 m/s in Chennai.

The temperatures at various positions are

**Table 3: Temperatures at Various Points in the Design**

| Locations | Temperatures |
|---|---|
| Inlet Temperature | 300K |
| Chimney Wall Temperature | 348K |
| Exhaust Temperature | 303K |
| Temperature at Inlet to Room | 299.22K |
| Temperature at a Random Point Inside the Room | 298.7K |

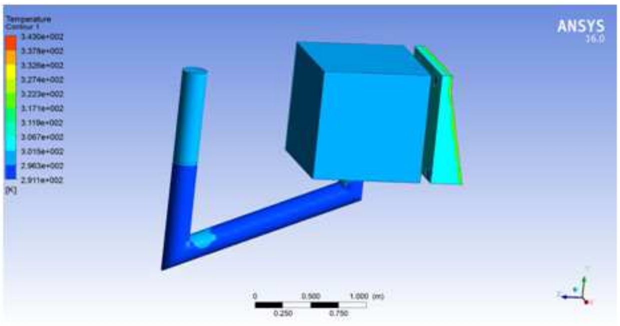



**Figure 5 (a): Temperature Contour**

Figure 5 (a), it is clear that the temperature of air is reducing while passing through the pipe. The temperature at the chimney is maintained at $70^0$C to create required pressure drop inside the chimney. Once the air in the chimney gets heated, it escapes through exhaust. The cool air coming to the room tries to decrease the room temperature. The reduction in the temperature observed is 2K.

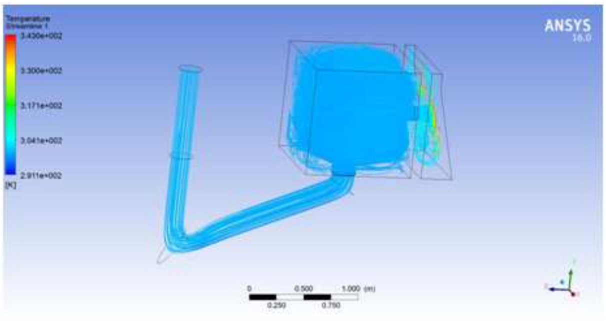



**Figure 5 (b): Temperature Contour of Streamline Flow**

Figure 5 (b), the streamlines of the flow are shown. The streamlines of air from the atmosphere to the chimney exhaust is shown in this figure. The flow throughout is taken as turbulent flow. So the cool air which is entering the room mixes with the air present in the room and attains the intermediate temperature between the temperatures of the cool air and the hot air.

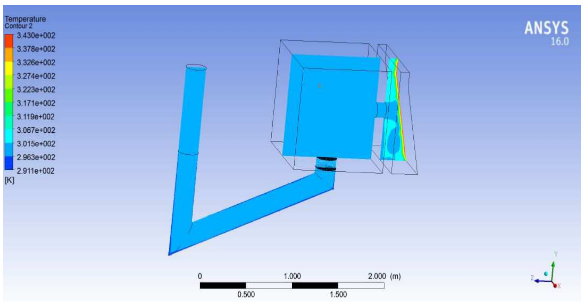



**Figure 5 (c): Temperature Contour of Random Plane**

Figure 5 (c), a plane is selected at mid position and a coloured contour was inserted into that. It helps us finding the temperature or pressure or velocity at particular point on the plane, in this case, the temperature is shown. A probe is placed at a random points and temperatures are noted at different places inside the room.

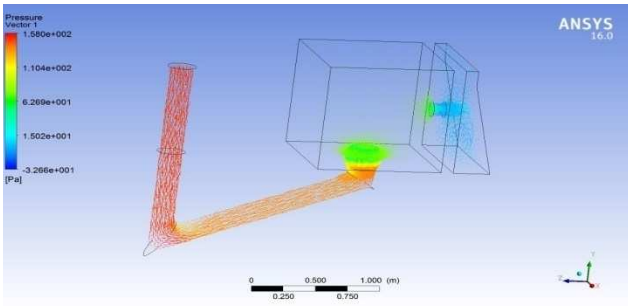



**Figure 6: Pressure Vectors**

Figure 6, the pressure lines are shown from the atmosphere to room to the chimney. The pressure at the inlet is very high and drops while passing along the pipe. The air has significant pressure at the inlet to the room for flow to take place. The pressure of air in the chimney is reduced by decreasing its density. Thus the flow takes place from inside room to the chimney exhaust. Flow takes place from high pressure region to low pressure region as we can see it in the above diagram.

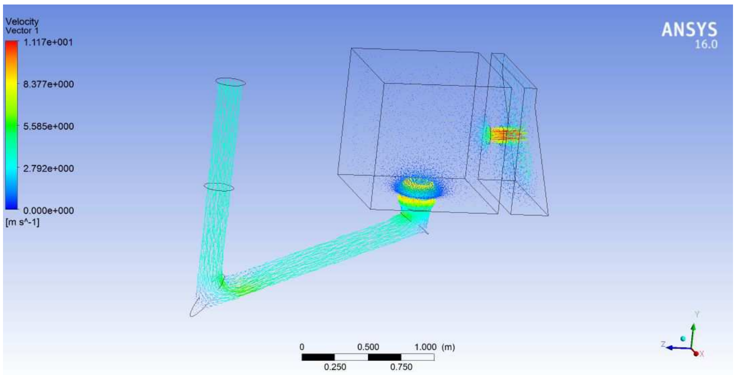



**Figure 7: Velocity Vectors**

Figure 7, the velocity vectors of the whole system is shown. The velocity of the air is observed as 3.44 m/s. The air enters the pipe and travels along the pipe and the velocity is getting reduced. At the inlet to the room, it's clear that the velocity of the air is minimum and thus the air slowly enters the room. Air present at the opening near chimney has medium velocity because this flow is induced by the chimney operation. Then the air escapes out through the chimney exhaust.

## CONCLUSIONS

For atmospheric temperature 300 K, wind velocity 3.48 m/s and the solar chimney wall temperature 348 K, the temperature observed inside the room is 298.7 K. The chimney exit temperature is nearly equals to the atmospheric temperature. The reduction in temperature inside the room depends on the thermal conductivity of the pipe which is under water. More the thermal conductivity, more the reduction in the temperature. In this case, the temperature of the chimney wall also decides the room temperature. Heat transfer from surroundings through walls depends upon the wall thickness of the room. If the wall thickness is more, the less heat from surroundings enters the room. By implementing this technique, we achieved about 1.5 K to 2 K of temperature reduction. For night cooling, a phase change material can be introduced in the chimney.

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